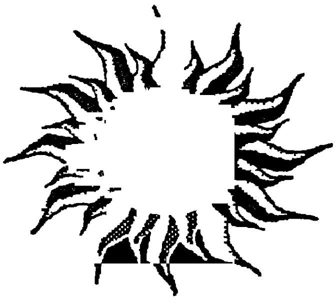
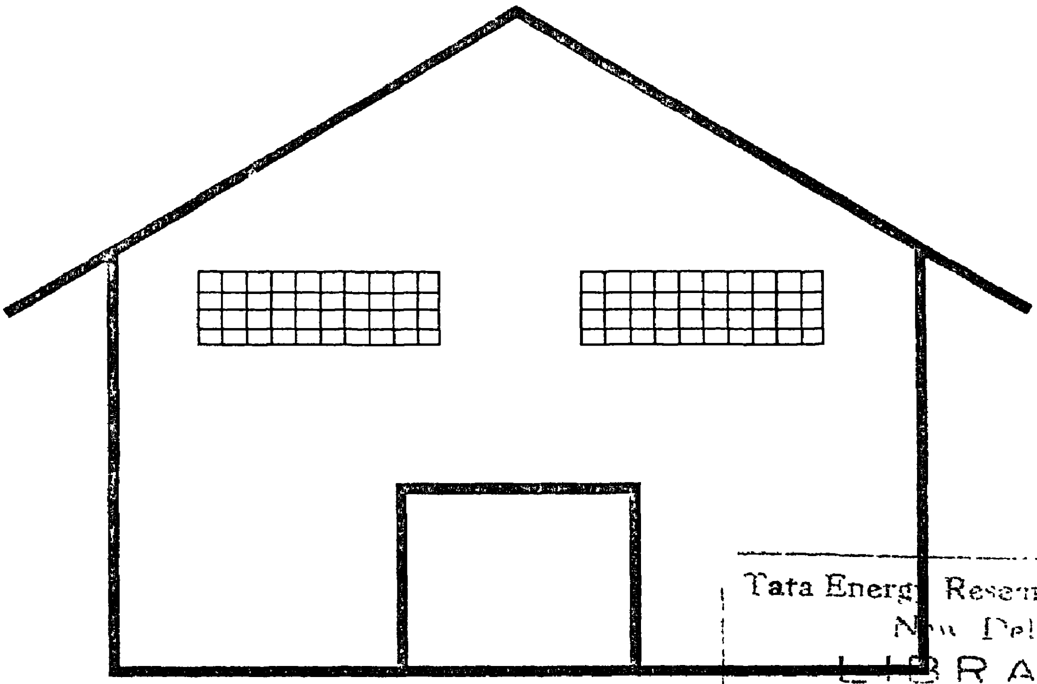
SOLAR PASSIVE ARCHITECTURE





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Arunachal Pradesh Energy Development Agency, Itanagar

1996

PROCEEDINGS OF WORKSHOP ON SOLAR PASSIVE ARCHITECTURE,
29TH MARCH 1996

SOLAR PASSIVE ARCHITECTURE STRATEGIES SYSTEMS AND DESIGNS

ARUNACHAL PRADESH ENERGY DEVELOPMENT AGENCY
GOVT. OF ARUNACHAL PRADESH

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PREFACE

(Proceedings of Solar Passive Architecture)

29th March '96, Itanagar.

The dependance on biomass fuels for cooking, space heating and lighting needs is overwhelming in Arunachal Pradesh. And with increasing population pressure and associated demand for energy intensive services, the energy resources of the state are under strees. The major end uses of space heating and lighting of homes and buildings have emerged as concerned issues today, as much of the total energy is consumed to provide adequate lighting and to heat spaces in buildings, including homes. The building industry is a great offender with its excessive use of fossil fuels in construction and operation. Conventional buildings do not use the resources of their natural environment and are rather dependent on high energy consuming materials. This is true of urban areas. In the rural areas, fuelwood is the main source of space heating and lighting and increased use of the same is resulting in the degradation of the biomass resources. The situation is more severe in the colder regions of the state, wherein space heating is necessary throughout the year.

In an attempt to reduce pressure on the use of conventional sources of energy and to encourage sustainable use of locally available resources, the concept of solar passive architecture is being promoted by APEDA. Solar Passive architecture has paved a way for using a relatively new concept of building houses etc. in which the interaction of the main cycles concerning the basic elements of soil, water, energy and air are carefully considered and transferred in to the design of buildings. Buildings designed with solar passive architecture techniques consider factors like natural lighting, natural ventilation and small zone climate controls resulting in increased productivity, low energy consumption and better health for its occupants. The incorporation of such techniques helps in creating a multi functional building ecosystem which is comfortable without causing environmental pollution. It also results in resource conservation by using renewable energy sources — Solar, Wind etc.

With a view to explore the scope of using solar passive architecture in the prevailing energy scenario of the state, APEDA organized a one day workshop on Solar Passive Architecture, which was attended by Administrators, Architects, Policy Makers, Technocrats, Researchers and Engineers to gain insights into this new concept. This publication is a compilation of papers on solar passive architecture which gives detailed account of developments in the field.

(K. C. Dhimole)
Director
APEDA, Itanagar

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Climatically responsive low energy architecture
(Keynote lecture)

Anil Misra, Tata Energy Research Institute, Lodhi Road, New Delhi- 110003

To make a building is to create a system linked to its surrounding environment and subject it to a range of interactions affected by seasonal and daily changes in climate and by the varying requirements of occupants in time and space.

The buildings as they are designed today seek to deny these inevitable interactions and subdue them with expensive heating, cooling and lighting equipment. We have become used to size and place these equipments as add-ons in more or less completed buildings. While this may be a pragmatic or convenient approach, it diminishes the opportunity to design buildings that can respond to the environment by virtue of their form and the intelligent use of materials with minimal reliance on machinery.

The excessive use of fossil fuel energy in building industry is high on the list of culprits. Energy used for airconditioning commercial buildings in India, for example, accounts for 32% of the total energy consumption (21,600 GWh in 1992) in the commercial sector. Several studies suggest that better design of new buildings could result in a 50% reduction in energy consumption; and that appropriate design interventions in the existing stock of buildings could yield energy reductions of 25%. Taken together and universally applied, these initiations could reduce the Indian energy bill up to Rs. 20 billion per annum (at present prices) and in a large number of cases can extend the level of indoor thermal comfort.

At present, the current building energy use trends are cause for concern because of lack of effective energy efficiency programs in the country. Uncertainties about energy use in buildings are echoed in the absence of adequate data for the building sector. Compared to industry and transportation, for the other major energy consuming sectors, country sources for energy statistics give little detailed information about buildings. Buildings often fall into the "other" category which lumps together the residential, commercial, public service and agriculture sectors. The limited coverage of the literature on energy standards reflects complexities inherent in analyzing both building energy use and building energy standards, specially in the private sector. These intricacies pose serious barriers to building energy research and complicate the development and usefulness of energy related standards.

An impediment to greater efficiency is also the fragmentation of the building trade. A commercial building project, for example, typically involves a series of hand offs: an architect designs the building but then hands it over to an engineer, who in turn specifies materials, systems and components, before passing responsibility to a contractor. Eventually the finished building is turned over to a maintenance and operations staff, who had virtually no say in the design process but probably know most about the building's day-to-day performance. In such a setting, initial construction costs are weighted much more heavily than long-term operating costs.

The system has to be improved. In the housing market, home buyers must learn to incorporate energy costs into their purchasing decisions and home builders need to exploit energy efficiency as a profitable product that consumers value. On the commercial side, attention must be paid not only to the design of the building but to the way in which it functions as a whole. Because energy costs over a building's life span are comparable to the initial costs of construction, an increase of only a few percent in efficiency still translates into a considerable sum of money.

The design and construction of a building, which takes optimal advantage of its environment, need not impose any significant extra cost, and compared to a more highly serviced building, it may be significantly cheaper to run. Higher design and material costs for better glazing, ventilation, lighting and insulation are offset by smaller (therefore cheaper) cooling and heating plant equipments. Smaller equipments and smaller ductwork means more net floor spaces. Therefore, the arguments in favour of having these buildings designed, built and operated so as to be optimally energy efficient are overwhelming.

A more climate sensitive approach, therefore, is required, which recognizes and responds to seasonal and daily changes in the environment for the well being and comfort of the occupants. The relationship among people, their living place and the environment needs to be re-examined and resolved in an architecture which permits a dynamic interaction to occur.

To achieve this calls for a knowledge of climate and an awareness of the available technologies which can be employed in buildings, combined with an understanding of what constitutes comfort and discomfort, and how these conditions can be affected by changes in climate. These issues are relevant to all buildings and locations, whether the predominant need is for heating, cooling or daylighting. Initial design decisions should focus on the location of the building, its basic form, the arrangement of spaces, the type of construction and the quality of the environment to be provided. These designs will then result in an architectural response of high quality, which is in harmony with its environment.

There are two major strategies depending upon regional climate and the predominant need for heating or cooling.

- In cold weather : Maximize "free" heat gains, create good heat distribution and suitable storage within the building and reduce heat losses, while allowing for sufficient ventilation.
- In warm weather : Minimize heat gains, avoid heating and optimize cool air ventilation and other forms of natural cooling, eg. earth compiling, direct or indirect evaporative cooling.

To the above must be added a daylighting strategy. The availability of daylight is influenced by latitude and climate. The use of natural light to replace electrical light is particularly important in large buildings with a low surface-to-volume ratio, where unwanted internal heat gains caused by artificial lighting can be considerable and often may require the use of mechanical airconditioning.

Good daylighting design will optimize the collection of natural light, ensuring its distribution about the building to provide lighting levels appropriate to each activity, while avoiding visual discomfort associated with high contrast or glare. The contribution which daylight can make to energy saving, visual comfort and the quality of the thermal living or working environment is relevant in all climates whether the predominant need is for heating or cooling.

In most situations, it is necessary to provide some additional heating or cooling at certain times. Similarly daylighting cannot meet all lighting requirements and therefore these auxiliary inputs and their controls must be addressed once the contributions by natural means and the patterns of use are known.

The design of an isolated building and its immediate environment where it is unaffected by neighboring buildings is one matter. However more often one must consider the negative and positive aspects of building in urban locations. Clusters of buildings create their own micro-climates through shading, shelter, wind deflection and the emission of heat. Depending on the climate, some of these aspects may be turned to advantage while others may have to be minimized. The interactions between buildings are, by nature very complex and the designer has to resort to design tools, guidelines and even more elaborate computer based tools in order to understand the phenomena involved and to predict how the building will perform.

In order to provide conditions of thermal comfort, a knowledge of the range of people's comfort tolerances is needed. Thermal comfort is affected by such factors as temperature, humidity, air movement, the level of physical activity and the amount of clothing being worn by the individual concerned. Comfort is to some extent subjective and consequently a capacity for the individual to have some control over his or her environment is desirable.

Hence one needs to demonstrate the benefits of an approach to the design of the buildings and their immediate surroundings which takes advantage of natural phenomenon instead of fighting the influences of nature with expensive and often environmentally destructive heating, cooling or lighting equipment and the energy they consume.

★★★

A case study on West Bengal Renewable Energy Development Agency

Planning and designing of the proposed Administrative Building cum office building at sector -V, Salt Lake City, Calcutta

S Banerjee, S P Pramanik, Gherzi Eastern Ltd., 43, Fazlul Haque Sarani, Calcutta

Preamble

West Bengal Renewable Energy Development Agency (WBREDA) is an organisation of the Dept. of Science and Technology, Govt.of West Bengal, with its present office at B-04, Block-LA, Sector-III, Salt Lake City, Calcutta. WBREDA is engaged in pioneering work in optimising energy consumption by solar passive architecture and the use of nonconventional energy sources in the state of West Bengal.

West Bengal Electronics Development Corporation has allotted a plot of land of about 11705 sq ft at Salt Lake City Electronics Complex, Block : ED, Sector -V, Plot : JI -10 for construction of their permanent office building to actually practice the methods of energy conservation and use of nonconventional energy by way of passive solar architecture.

Since office buildings consume bulk amount of power, to reduce this, WBREDA has decided to incorporate energy efficient architecture, low wattage luminaries, automatic switching of lighting system and use of other nonconventional energy sources. To facilitate such energy efficiency the buildings are to be designed incorporating components of solar passive architecture. The building layout, internal planning and selection of material will be of major importance to help conserve the power consumption as well as in using the nature's abundance of energy in the most useful way by way of illumination, heat transmission and aircirculation.

For the above WBREDA has engaged M/S Gherzi Eastern Ltd., having its head office at Neville House, J.N.Heredia Marg, Ballard Estate, Bombay and Eastern Regional Office at 43, Fazlul Haque Sarani, Calcutta as Architect and Consultant for the project. M/S Gherzi Eastern Ltd. has tied up with Tata Energy Research Institute, Lodhi Road, New Delhi for obtaining data analysis for preparing this detailed project report and for optimisation of the design of total work.

Site

The site is at the eastern periphery of Calcutta Metropolis and the area is located within the Salt Lake City Electronics Complex, Block-ED, Sector -V, Plot -JI -10. The Salt Lake City being a newly planned urban complex, also provides ample opportunities to plan and design climatic responsive and energy efficient buildings.

Climatic parameters

Calcutta is situated at approximately 22° North latitude and 88° East longitude. According to published metrological data available at Calcutta, the location of the site falls in warm humid region which is characterized by the following,

Climate	Mean monthly temp.	Relative humidity	Precipitation	No.of clear days
Warm&humid	>30° C	>55 %	>5 mm	<20/month

The day to day metrological data are to be obtained for a closer examination after which the above classification may be modified. The maximum average monthly temperature does not exceed 40°C. Maximum relative humidity is 95% with the minimum relative humidity being 55%. The maximum precipitation is 1600 mm. Sunshine days are more than 20 days per month with more than 9 hours of sunshine a day. Thus it can be concluded that climate of the area can be classified as composite with an extended warm humid period.

Climatic analysis

Winds

The summer wind is mostly from the south and south-west direction with secondary wind from the north-east. The winter wind direction is from the north-west and north with secondary wind from the north-east.

The wind speed in summer and warm humid period is expected to be low except for periods of occasional stormy weather. The wind speed in winter is extremely low with heavy cloudy effect during the period.

Comfort chart evaluation

Monthly comfort condition indicates the following,

November to February - These are the months which lie in, somewhat, the comfort zone, however minimal heating during the nights for a few days is required.

March to October -Day time comfort conditions mostly lie in the warm and humid zone between March and June when minimal cooling is required, and between June and October requiring ventilation at the rate of 3m/sec for attaining comfort conditions.

Design strategy

Summer (warm and humid period)

This is the extended critical period of design requiring high level of ventilation as the night time temperatures are also relatively high and will require extra electrical power for cooling auxiliary systems in a normal building. Therefore to maximize the use of natural resources, the solar passive architectural design strategy can be adopted.

- Minimising heat gain through appropriate building exposure.
- Use of thermal inertia of the ground.
- Maximum direct and indirect ventilation.
- Utilisation of water body for lowering of trapped wind by way of architecture orientation.
- Day lighting and energy implication.

Winter

The winter period is mostly comfortable during day time which does not require any auxiliary heating though during the nights, requirement of minimum heating is present. The building being an office building, no heating is required for the nights.

Warm and humid period

It has a long extended period of hot humid conditions. The maximum precipitation also occurs during this period. Strategy of design for this period is to maximize ventilation and minimize heat gain through the building fabric.

Solar passive strategies and systems adopted

To maximise the utilisation of natural resources the following strategies and systems have been adopted,

- The building being on open flat land the orientation of the building was carefully selected with least exposed faces on west and east directions.
- The longer faces of building being south and north facing are exposed to direct winds from these directions.
- Due to high water table and soil conditions, underground construction could not be undertaken but the thermal inertia of ground by earth embankment upto window sill level has been adopted in west and north face.
- A water body is created within the building in the south-southwest location to have the direct wind trapped, cooled naturally and vented through the non airconditioned area of the building. A provision for a solar chimney system was also made.

- Direct ventilation in the ground floor area to provide naturally cooled air circulation by providing suitably situated windows.

- Heat gain from the west facing wall as well as the east facing wall which is exposed to heat in the high summer was minimized by adopting cavity wall. A study conducted showed superiority of providing PUF insulation or glass wool insulation in a single wall, avoiding complicated construction of the cavity wall.

- All corridors are to be ventilated by solar chimney and energy consumption minimized in day time by providing low Eglass mumties.

- White ceramic tiles on external finish will minimize direct heat gain.

- Roof treatment will be finished with broken glazed tiles to minimize direct heat gain from the top.

Day light distribution

Day light distribution is a very efficient means of minimizing electrical energy used for artificial lighting during the day specially for office buildings.

Provision of direct daylight in all spaces through direct windows has been made possible through architectural design. By way of innovated raised roofing, the corridors of the office spaces have been provided with sunlight from the top. While designing the windows efforts have been made to have the highest lighting effect either directly or by way of reflection from the ceiling and cutting off heat rays by suitably designing the horizontal and vertical blinds with appropriate angles. The vertical blinds can be made mechanically adjustable to allow the direct sunlight to working areas only. Airconditioned areas have been located strategically on the north side to have maximum utilisation of north lights as it will reduce the energy consumption for lights and heat gain from lights inside.

Main feature of the design

1. Building orientation has been carefully selected to minimize heat gain and maximize utilisation of natural ventilation and daylight.
2. Creation of water body for cooling of south breeze during the warm and humid period to cool the exhibition space naturally.
3. Use of solar chimney for natural lighting and cross ventilation of non airconditioned areas.

Auxiliary systems

- Summer shading device is being adopted by providing large and long shadowing trees to prevent late west sun on the building.

- The building shadowing is being done by providing adequate overhangs on the windows.

- Areas of heat collection such as large glass windows for cross ventilation are provided in the shadow areas.

- Providing large air ducts by way of long tunnel shaped corridors with openings under shade wall provides adequate heat radiation.

- As the building is in warm and humid region, heat storage elements of the building are to be avoided.

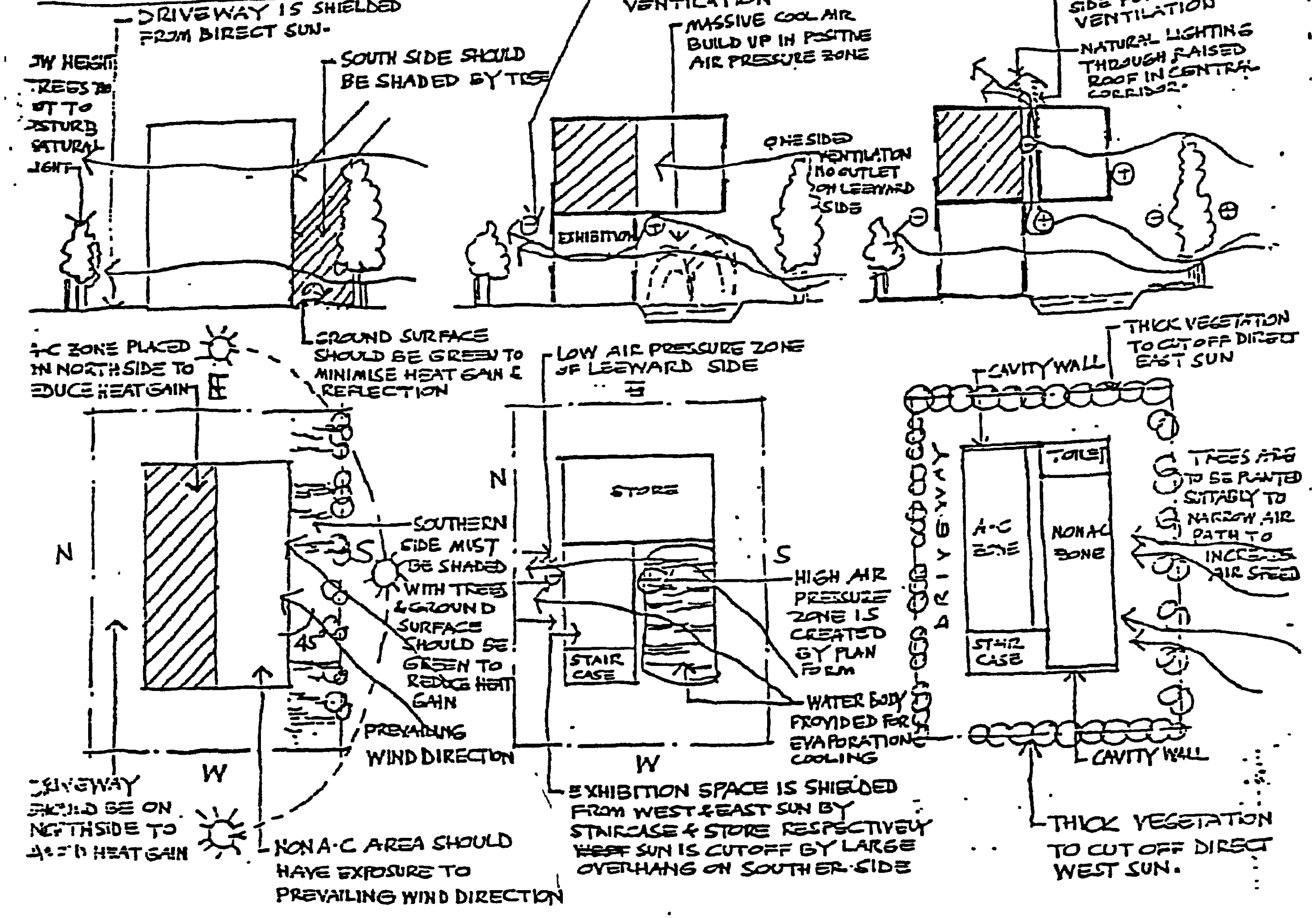
- Selection of finishing materials, colours of the building and open spaces are to be carefully selected for least heat storage.

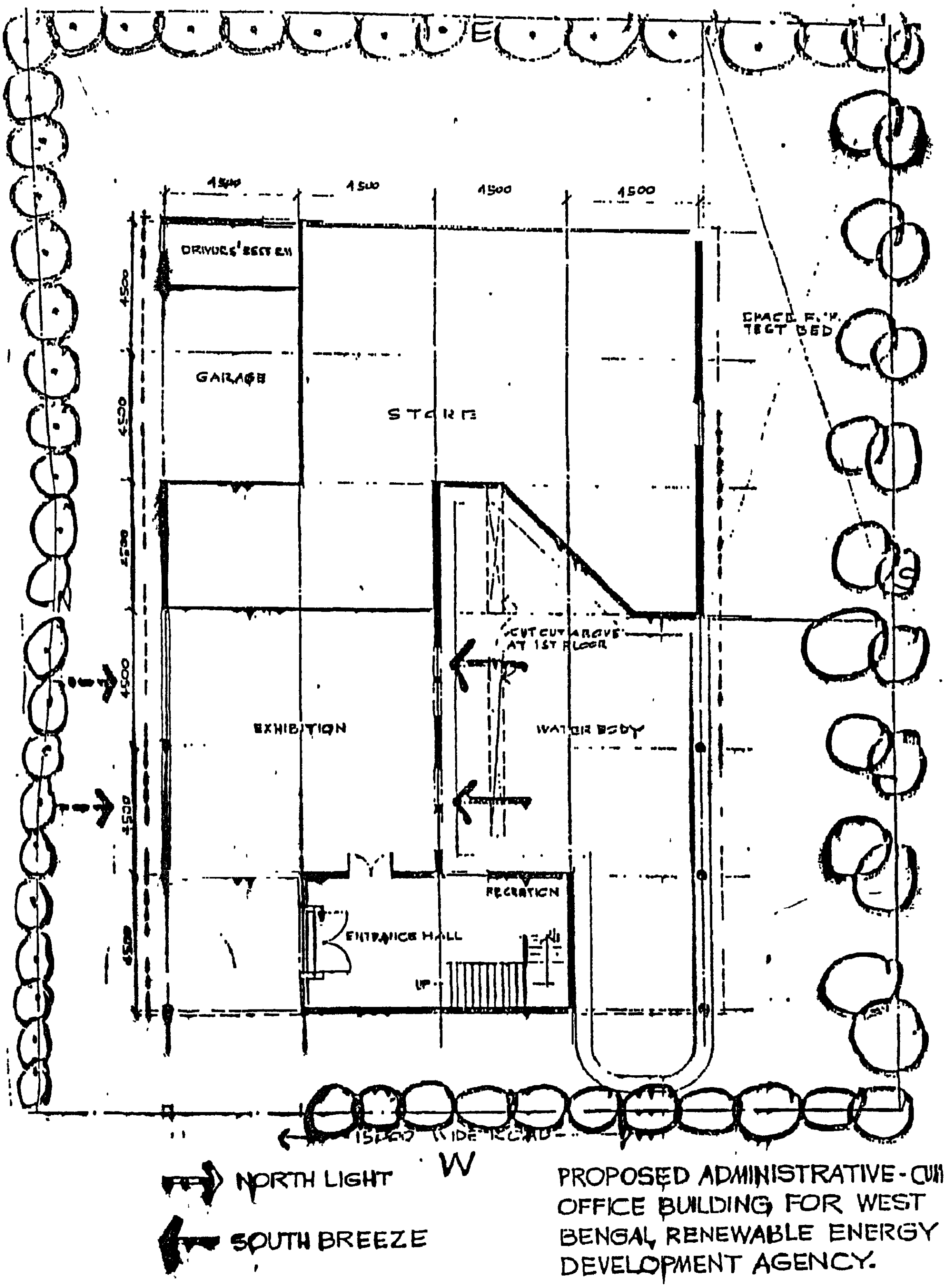
Conclusion

The administrative building cum office for the WBREDA has thus been planned and designed on the methodology of solar passive architecture. Cost estimate of the building with the ground and first floors have only been done on the basis of the preliminary project drawings prepared, and the same works out to be approximately Rs. 100 lakhs.

In view of the proposed energy audit to be done by Tata Energy Research Institute, New Delhi, the cost of the building, particularly the cost of airconditioning is expected to be reduced by 20%. While on the subject, it may be a point to be noted that in the Eastern Region we do not have the required data

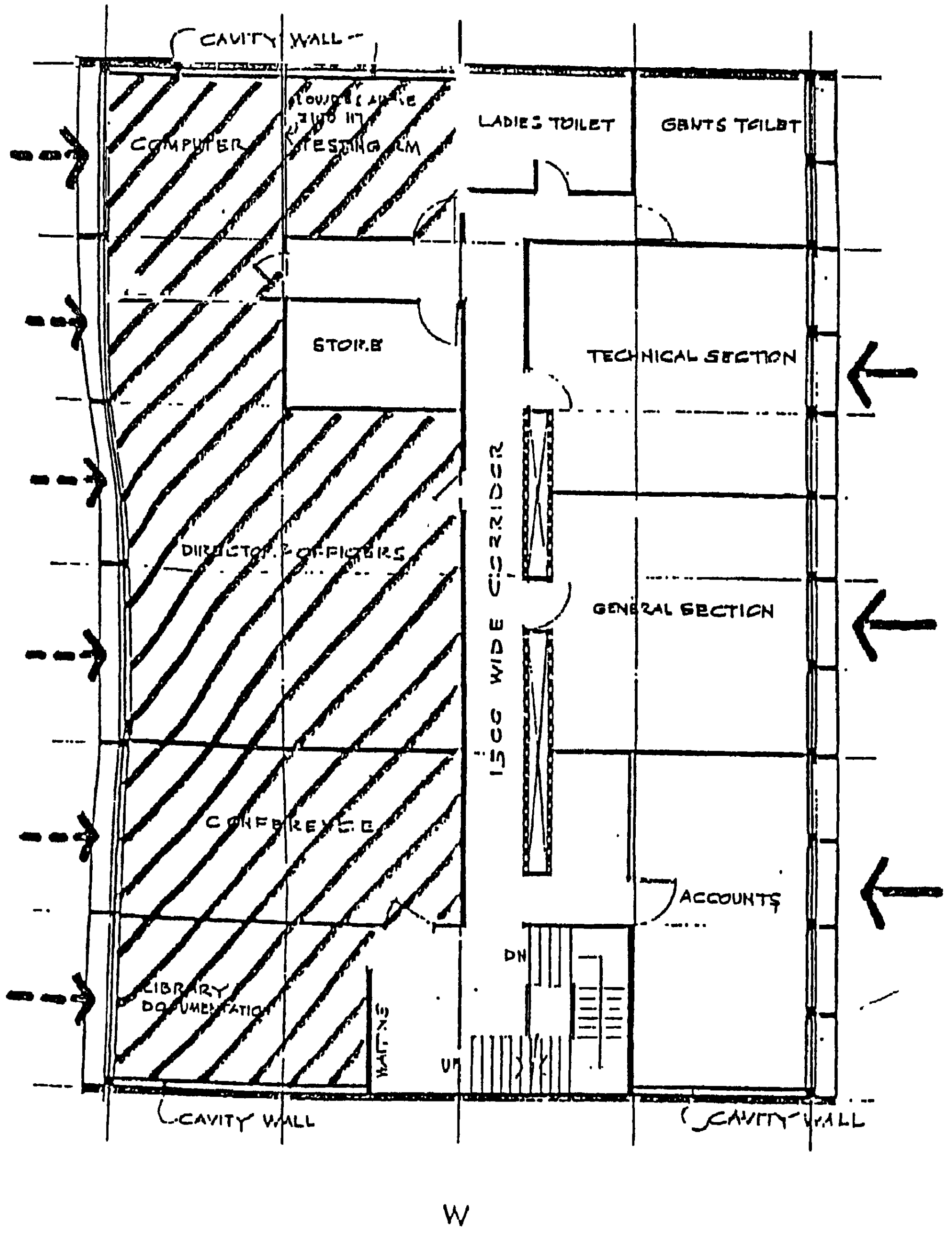
EVOLUTION OF CONCEPT


DRIVEWAY IS SHIELDED FROM DIRECT SUN.
W HEIGHT TREES TO T TO STURB ATURAL LIGHT
SOUTH SIDE SHOULD BE SHADED BY TREE
LARGE OPENINGS ON LEEWARD SIDE TO ENHANCE VENTILATION
MASSIVE COOL AIR BUILD UP IN POSITIVE AIR PRESSURE ZONE
ONE SIDED VENTILATION NO OUTLET ON LEEWARD SIDE
EXHIBITION
RAISED ROOF WITH OPENING ON LEEWARD SIDE FOR NATURAL VENTILATION
NATURAL LIGHTING THROUGH RAISED ROOF IN CENTRAL CORRIDOR.
A-C ZONE PLACED IN NORTH SIDE TO EDUCE HEAT GAIN
E
GROUND SURFACE SHOULD BE GREEN TO MINIMISE HEAT GAIN & REFLECTION
N
S
W
45°
SOUTHERN SIDE MUST BE SHADED WITH TREES & GROUND SURFACE SHOULD BE GREEN TO REDUCE HEAT GAIN
PREVAILING WIND DIRECTION
DRIVEWAY SHOULD BE ON NORTH SIDE TO AVOID HEAT GAIN
NON A·C AREA SHOULD HAVE EXPOSURE TO PREVAILING WIND DIRECTION
LOW AIR PRESSURE ZONE OF LEEWARD SIDE
E
N
S
W
STORE
STAIR CASE
HIGH AIR PRESSURE ZONE IS CREATED BY PLAN FORM
WATER BODY PROVIDED FOR EVAPORATION COOLING
EXHIBITION SPACE IS SHIELDED FROM WEST & EAST SUN BY STAIRCASE & STORE RESPECTIVELY ~~WEST~~ SUN IS CUTOFF BY LARGE OVERHANG ON SOUTHER SIDE
THICK VEGETATION TO CUT OFF DIRECT EAST SUN
CAVITY WALL
TOILET
A-C ZONE
NON A-C ZONE
STAIR CASE
DRIVEWAY
TREES ARE TO BE PLANTED SUITABLY TO NARROW AIR PATH TO INCREASE AIR SPEED
CAVITY WALL
THICK VEGETATION TO CUT OFF DIRECT WEST SUN.



PROPOSED ADMINISTRATIVE-CUM OFFICE BUILDING FOR WEST BENGAL RENEWABLE ENERGY DEVELOPMENT AGENCY.

CONSULTANT- GHERZI EASTERN LTD



▨ AIR CONDITIONED AREA

→ NORTH LIGHT

← SOUTH BREEZE

PROPOSED ADMINISTRATIVE-CUM-
OFFICE BUILDING FOR WEST
BENGAL RENEWABLE ENERGY
DEVELOPMENT AGENCY.

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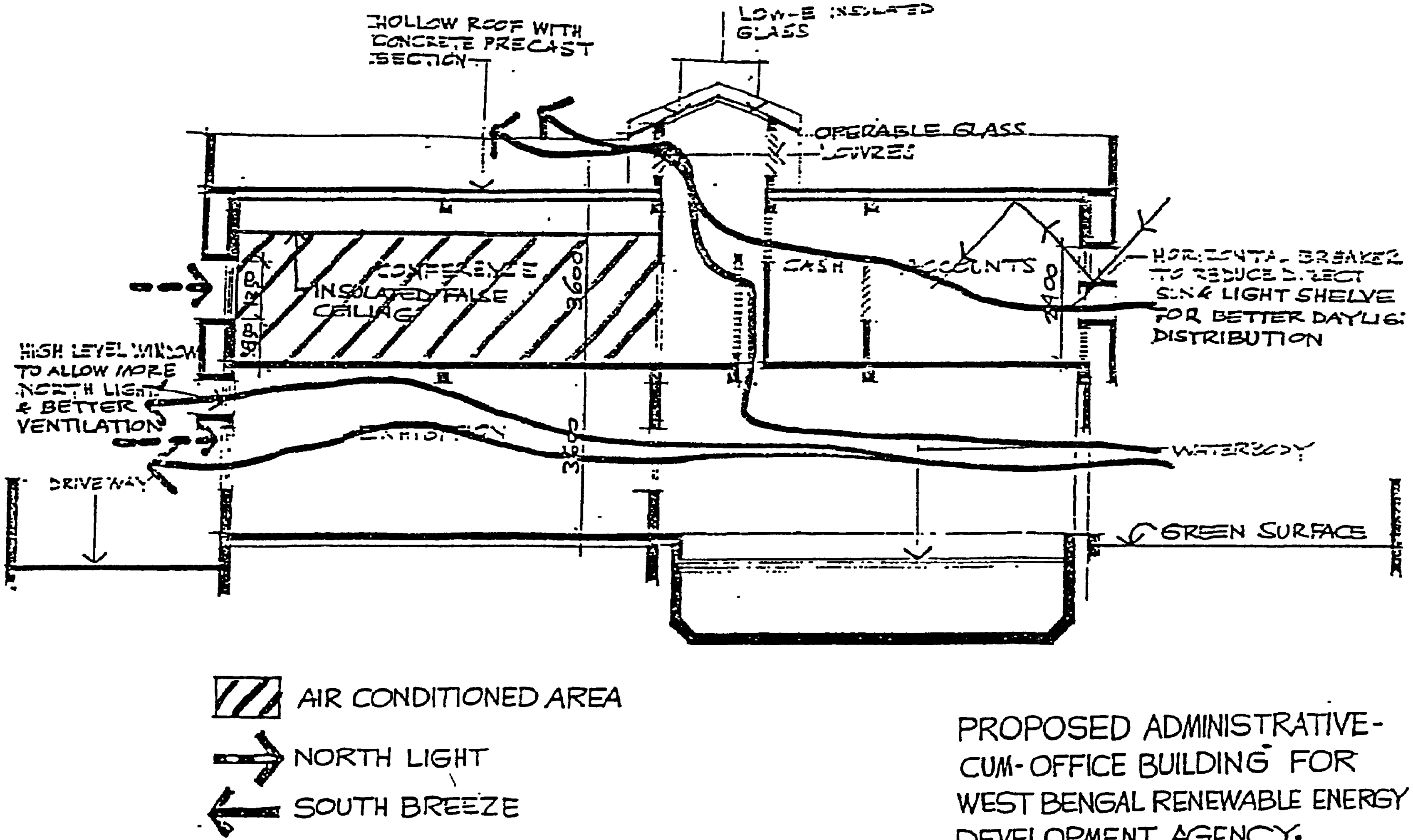
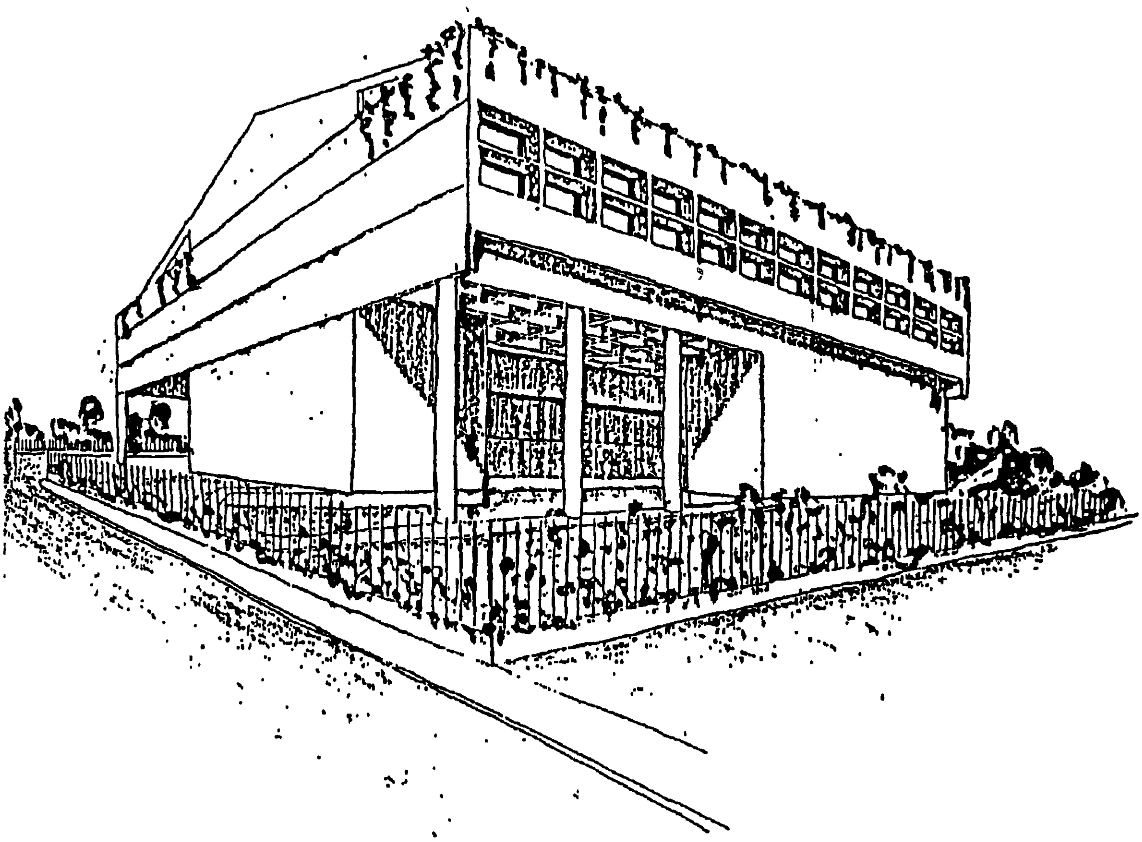

HOLLOW ROOF WITH CONCRETE PRECAST SECTION
LOW-E INSULATED GLASS
OPERABLE GLASS LOUVRES
HORIZONTAL BREAKER TO REDUCE DIRECT SUN & LIGHT SHELVE FOR BETTER DAYLIG. DISTRIBUTION
CONFERENCE
INSOLATED FALSE CEILING
3600
CASH
ACCOUNTS
2400
HIGH LEVEL WINDOW TO ALLOW MORE NORTH LIGHT & BETTER VENTILATION
EXHIBITION
3600
WATERBODY
DRIVE WAY
GREEN SURFACE
AIR CONDITIONED AREA
NORTH LIGHT
SOUTH BREEZE

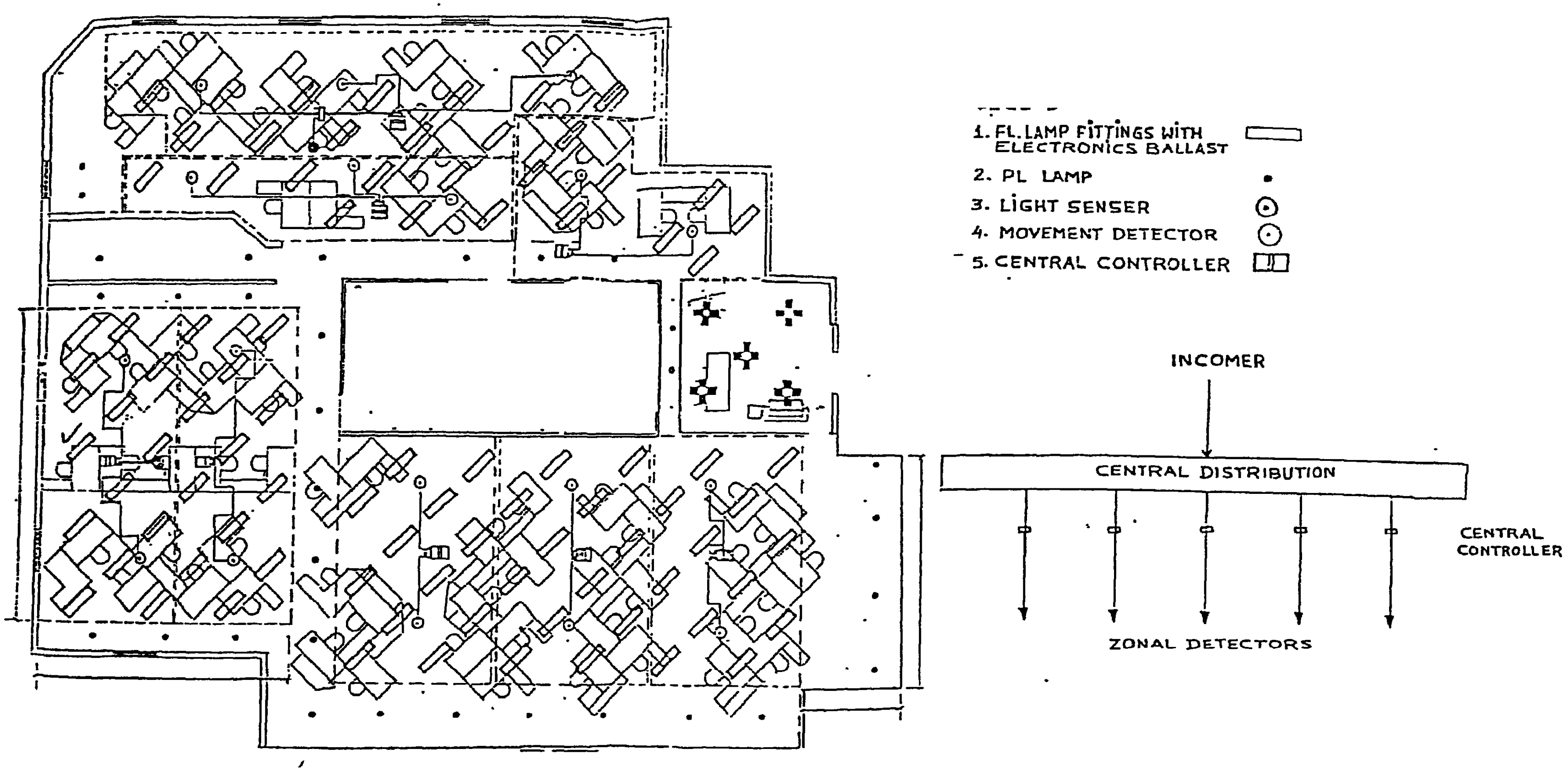
PROPOSED ADMINISTRATIVE-
CUM-OFFICE BUILDING FOR
WEST BENGAL RENEWABLE ENERGY
DEVELOPMENT AGENCY.
CONSULTANT-GHERZI EASTERN LTD



PROPOSED ADMINISTRATIVE CUM OFFICE BUILDING FOR WEST BENGAL RENEWABLE ENERGY DEVELOPMENT AGENCY.

CONSULTANT- GHERZI EASTERN LTD

DRG NO- GE/WBREDA/07


1. FL. LAMP FITTINGS WITH ELECTRONICS BALLAST
2. PL LAMP
3. LIGHT SENSER
4. MOVEMENT DETECTOR
5. CENTRAL CONTROLLER
INCOMER
CENTRAL DISTRIBUTION
CENTRAL CONTROLLER
ZONAL DETECTORS

centre for general consumption. We have to depend on Meteorological Data Centre, Pune for the data of the recent past. The published data change by the time they are used. Therefore developing a climatic data centre in the Eastern Region would go a long way in utilizing solar passive methodologies in day to day architectural involvement of common man.

Energy conservation in solar passive building

Although solar passive architectural building reduces energy consumption by proper manipulation of the following elements for ultimate requirement :

a) building orientation;

b) construction practices; and

c) use of passive energy source

But still some areas remain unidentified, which contribute towards substantial power consumption, specially in commercial/office establishment.

A considerable amount of electricity is consumed/utilized in commercial buildings for lighting, ventilation, space airconditioning, heating, lift and other gadgets and appliances of which lighting load is most vital.

Although proper selection of luminaries is of vital importance, but controlling of internal lighting in respect to external sunlight contribution is another factor.

Although the lighting system is designed assuming contribution from external source of light/sunlight, but during daytime certain contribution is always expected from sunlight source through windows etc. The net effect of this excess light in same period results in energy wastage.

Table A : Hourly external lighting contribution in a commercial area/office through windows.

Time	9am	10am	11am	12 N	1pm	2pm	3pm	4pm	5pm	6-8pm
external light(%)	10%	25%	25%	25%	25%	15%	10%	5%	2%	Nil

Average sunlight contribution : 12.9%

Hence a 12.9% saving in lighting costs can be achieved by this daylight linkage.

Another source of loss is lighting in the non-occupancy zone, specially in chambers. In most commercial complexes light is switched much be fore personnel step into the office.

Full lighting is on irrespective of presence or absence of working personnel in any particular area. Also the entire luminaries are on till the last person has left the office.

Table B : Hourly occupancy (%) of personnel in a typical office

Time	9am	10am	11am	12 N	1pm	2pm	3pm	4pm	5pm	6-8pm
occupancy in %	10%	95%	95%	95%	90%	50%	90%	95%	95%	5%

From the above table it is clear that automatic switching ON and OFF lights will automatically reduce power consumption.

To achieve this the total office space and chambers are being sub-divided into modules. Each module is being controlled by a control unit of microchip controller and has the ability to switch ON/OFF lights.

This central unit also receives information feed-backs from :

a) Daylight linkage sensor

b) Area occupancy through movement sensor

The daylight linkage sensor switches off luminaries in the module if light intensity is more than the predetermined limit. The movement sensing detector luminaries will be automatically switched on in a particular area when movement is detected. If movement is detected within any module over a preset period of time all luminaries within the module will be switched off automatically. The above sensors are mounted on ceilings.

★★★

Passive Solar Rowhouses

Burke Miller Thayer, American Solar Energy Society, 2400 Central Avenue, Unit G-1, Boulder, Colorado 80301, USA.

For the past ten years, a housing development in North Philadelphia has been quietly making a statement about sustainability in American cities.The 23 rowhouses on the 1500 block of Thompson street, though similar in many ways to other homes in the neighborhood, stand out as models of low energy use. These 2-storey 1280 ft^2(119 m^2) energy-saving homes are designed and built to use the sun as their main source of heat.

Developed by the National Temple Non-Profit Corporation and designed by Campbell Thomas & Company architects, the Thompson Street passive rowhouses cost about $70,000 each to build in 1984. A Department of Housing and Urban Development (HUD) grant, provided under an urban revitalization program, enabled buyers to purchase the homes for about $35,000. National Temple's goal, supported by HUD, was to encourage people to move back into this part of North Philadelphia by making new housing available at an affordable price.

The architects demonstrated to HUD and the developers that they could achieve significant energy savings through passive solar design at no extra cost. And although the rowhouses are now ten years old, they still use almost two-thirds less energy to heat than similar-style conventional rowhouses being built today. This kind of energy savings can make a difference for low and moderate-income first-time homeowners struggling to make ends meet in city neighborhoods.

Homeowners Vivian and Larry VanStory, who live in one of the corner homes in the development, spend about half as much on heating as many of their neighbors living in non-solar homes. Along with the money they save, the VanStorys appreciate the bright, cheery atmosphere of their home. Vivian says she rarely turns lights on during the day, and she loves the open feeling of the high ceilings and the light coming from the clerestory windows.

Starting with Energy Efficiency

In their design for the Thompson Street solar rowhouses, the Campbell Thomas architects began with cost-effective strategies for creating an energy-efficient home. The R-25 walls are 8-inch (20-cm.) concrete block, insulated on the outside with 4 inches (10 cm) of extruded polystyrene. The polystyrene is covered with a fiberglass stucco-like material, which is stronger and more durable than traditional stucco. This simple approach to wall construction achieves about 50 percent higher insulating value than standard approaches. It also avoids "thermal bridging," a drawback of wood-framed walls. Thermal bridging occurs where insulation-filled wall cavities are separated by evenly spaced wood studs. The insulating value of the wall is diminished at each stud, where heat can be more easily transferred from the inside space through the stud (the "bridge") to the outside. The high, sloped ceilings in each rowhouse are insulated with fiberglass batts to an R-value of 30 and all windows are double-glazed. Each home has an airlock entry, which keeps the living space from ever having to be open to the outside cold air. The wall construction and stuccolike finish, combined with careful caulking around window and door openings, help to minimize air infiltration.

Passive Solar Features

The continuous row of 23 single-family attached homes runs along an east/west axis with the front of the house (street side) facing north and the backside facing south and overlooking a yard/garden area. South facing windows in the kitchen/dining area and an upstairs bedroom admit direct low angle sunshine in the winter months. This window area totals about 84 ft^2 (7.8 m^2). Clerestory windows above the other two bedrooms add another 48 ft^2 (4.5 m^2) of south-facing glass. The clerestory and south-wall windows provide direct solar gain to four of the home's five main living spaces, evenly distributing the benefits of solar heating and daylighting.

Besides providing direct solar gain to the bedrooms, the clerestory windows help reduce the need for air conditioning in the summer. Residents can open the high windows to vent warm air from the house. An operable skylight in the bathroom serves a similar purpose.

On the portions of the south-facing facade where there is no direct gain glazing, 128 ft^2 (11.9 m^2) of Trombe walls provide additional solar heating. The Trombe walls are portions of the 8-inch (20-cm) concrete exterior blockwalls combined with plastic glazing and a 4 inch (10-cm) air space. The concrete block is filled solid and is painted black to more efficiently absorb the sun's rays. Vents in the bottom and top of the trombe walls allow air to circulate between the adjoining room and the space between the wall and the plastic glazing (see illustration). As the sun warms the airspace between the glazing and the Trombe wall the warmed air rises into the room through the upper vents. Cooler air from the room is pulled into the air space through the lower vents, heated, and returned to the room. In additional to this daytime warming effect, the concrete mass in the Trombe wall absorbs heat during the day to be released into the living space in the evening as the room cools down.

While the architects made the most of the south-facing portions of the homes for solar collection, they also minimized the heat loss from the north by limiting the size and number of north-facing windows. And with the exception of the two end houses, none of the homes has east or west outside walls or windows to lose heat or admit unwanted solar gain.

Energy performance

Each of the rowhouses, with the exception of the two corner homes,requires only 6800 Btu/ft^2/yr(74 million joules/m^2/yr) for heating. This is almost two-thirds less than what a non-solar, conventionally designed, insulated and constructed rowhouse of identical dimensions would need. The calculated heating load for the reference case home is about 18,400 Btu/ft^2/yr (209/million joules/m^2/yr).The energy efficiency features alone account for a 45 percent difference in energy load between the solar home and the reference case-a reduction of 7,300 Btu/ft^2/yr (83 million joules/m^2,bringing the total savings to 63 percent.To arrive at the loads for both the solar and hypothetical reference rowhouse, we used the Builder Guide software created by the National Renewable Energy Laboratory to evaluate the energy impacts of various design features.

Although we were not able to quantify a reduction in cooling load for the solar homes versus conventional rowhouses, residents reports that the clerestory windows, which vent hot air in summer-time, reduce the need of air conditioning. Clerestory windows also provide natural lighting in a middle room that would otherwise have no windows because of constraints of rowhouse construction.

Within the Budget

The National Temple rowhouse development had a set budget of $70,000 (1984) per home, which they required the architects to stay within. According to Bob Thomas, the partner in charge of the project, this meant that he had to incorporate solar features and efficiency improvements at no additional cost. In order to do this, he chose to install electric baseboard heating, individually controlled in each room, instead of a central natural gas furnace. The initial cost of the electric back-up heat is about $ 2,500 less than a natural gas system with a furnace and ductwork.

Although electricity is a more costly heating fuel than natural gas, the solar design reduced the need for heating to the point where it made sense to use electricity. If the individual thermostats controlling the electric baseboard heat in every room were set to heat all rooms to a comfortable temperature at all times, the annual heating cost would be about $340. But because the thermostats can be easily turned off or down in individual rooms (for example, in rooms that are seldom used or not used during the day), and because the heatup time is short once a thermostat is turned on, residents actually spend considerably less than this amount. Their actual heating bills range between about $150 and $180 each year. Because a natural gas forced air system is not as easy to fine tune to the needs of individual rooms, it typically keeps all rooms in the house at a relatively constant temperature. The cost of heating the reference case home with natural gas is about $310/ year. The net savings for the solar home is therefore about $130- the difference between the $310 estimated natural gas costs for the reference case and the $180 actual electricity costs for the solar homes per year.

The cost of residential electricity in Philadelphia is 13.5 cents/kilowatt hour. This is one of the highest rates in the country. In most regions of the US, electricity costs are one-half to two-thirds of this rate. Natural gas costs, on the other hand, are less variable. Therefore, if we were to make a comparison between the Campbell Thomas rowhouse design (electric) and the reference case (natural) in another city, the solar rowhouse might save considerably more money than it does in Philadelphia. For example, in another location, the solar house might only cost two-thirds of the $180 or $120 it costs to heat in Philadelphia. Compared to the $310/yr cost of natural gas for the reference case, this is an even greater savings of $190 ($310 minus $120).

Improving performance

In an initial-cost tradeoff, the architects balanced the clerestory windows, which were the most expensive solar feature in the rowhouse design, with low initial-cost baseboard heating. Although the clerestories provide daylighting and cooling benefits, they contribute only a small amount to heating performance. An alternate design option (emphasizing heating savings as the most important consideration) would be to eliminate the clerestory windows and install natural gas back-up heat instead of electric baseboard heaters. The combination of energy efficiency, direct gain and Trombe walls alone reduce heating needs by 62 percent. The annual heating bill for the redesigned solar home (no clerestories and natural-gas-heated) would then be about $120 in comparison to the $310 for the reference case. This would result in a $60 savings over the $180 annual cost for the Thomas Campbell design (with clerestories and electric baseboard heat).

The architects chose to use circulating Trombe walls in their Thompson Street project. A circulating Trombe wall is one in which vents in the concrete wall cause air to flow between the heated air space and the room. Research over the past decade has shown that non-circulating (no vents to the inside) Trombe walls with selective surface facing (which facilitate more rapid heat absorption) increase heating performance significantly over circulating Trombe walls. The non-circulating Trombe walls store more heat for release in the evening and avoid potential problems with reverse natural circulation that can occur at night and during cloudy periods. The alternative approach to Trombe wall design could improve the performance of the solar rowhouses even more.

Model for the future

Although the Campbell Thomas architects had a relatively easy time convincing the National Temple Corporation of the practicality and benefits of solar design for low to middle income rowhousing, finding a bank to finance the project was more difficult. The non-profit developers finally found financing through a state of Pennsylvania Department of Community Affairs grant. And once banks saw how successful the project was, several were eager to help with future projects. Unfortunately, government dollars to assist with housing in economically depressed areas in Philadelphia essentially dried up in the late eighties.

The solar rowhouses, however, stand as an example of what can be done to build affordable multi-family housing.

If the Thompson Street project is any indication, our cities offer tremendous potential for creating energy efficient, solar heated homes that save homeowners money and help our country move away from dependence on fossil fuels. Building these types of homes takes us further down the road toward meeting our nation's environmental and economic goals.

The ASES/PSIC Buildings for a Sustainable American Education Campaign is a nationwide effort to make policymakers, building professionals and consumers more aware of the benefits of applying sustainable energy principles to building design and construction. The benefits include increased affordability, more jobs, improved health, reduced energy consumption and less environmental impact.

Here's the Thompson street solar rowhouses stack up:

Energy

63% overall reduction in energy use for heating

Affordability

When compared with a reference case, the solar rowhouses save an estimated $130 per year in space heating bills at no added cost. An alternate solar design, leaving out the clerestory windows and including natural gas heat would result in a saving of about $190/yr.

Jobs and economy

Because the residents of the solar rowhouses are spending less on utility bills, they have more money to spend with local businesses, which strengthens their local economy. Money spent this way, instead on energy bills, creates a net increase in jobs because the great majority of industries, including construction and manufacturing, are more labor intensive than the energy industry.

Health and productivity

The passive solar features of the Campbell Thomas-designed rowhouses contribute to a feeling of comfort, cheeriness and a connection to the outdoors as a result of the heating and lighting effects of the sun. These qualities in a home are conductive to more positive outlook and feelings about one's living environment. The absence of combustion appliances in the homes also reduces the potential negative health impacts of indoor air pollution.

Environment

The reduction in electricity use for the solar rowhouses helps minimize the environment impacts of power plant operations, including air emissions from coal combustion and radioactive waste from nuclear plants. And because most Philadelphia homes use natural gas for heating, the solar design reduces the relative environmental impact of natural gas use, from exploration to combustion.

Solar Rowhouse Project Details

Project description	: 23-home passive solar rowhouse complex
Architect	: Campbell Thomas & Co. Architects 1504 South street, Philadelphia, Pennsylvania 19146, (215) 545-1076
Developer	: National Temple Non-Profit Corporation
Location	: Philadelphia, Pennsylvania
Size	: Each unit 2 storey, 3 bedroom, 1280 ft^2 (119m^2)
Construction cost	: $70,000 (1984 actual cost)

Year completed	: 1984
Heating degree Days	: 4947
Cooling Degree Days	: 1075

ENERGY PERFORMANCE

	Reference	Solar Rowhouse	Reduction
Heating Load	18,400 Btu/ft^2/yr	6,800 Btu/ft^2/yr	63%

Energy efficiency accounts for the first 7,300 Btu/ft^2/yr (83 million joules/m^2/yr) of load reduction. Passive solar features account for the remaining reduction of 4,300 Btu/ft^2/yr (49 million joules/m^2/yr).

The heating load, after accounting only for energy efficiency improvements, is 11,100 Btu/ft^2/yr (126 million joules/m^2/yr). Passive solar features meet 38 percent of this load. An electric baseboard auxiliary heating system with individual thermostats in each room provides the remainder.

Solar features

- South-facing glass, including clerestory windows: 132 ft^2 (12.3 m^2)
- South-facing Trombe walls: 128 ft^2 (11.9 m^2)
- Through ventilation pattern for natural cooling
- Thermal mass in the concrete block walls and concrete slab

Energy efficiency/conservation features

- R-30 ceiling (fiberglass batts)
- R-25 walls (8 inch concrete block, 4 inches exterior insulation and finish system)
- Air lock entry, sealing and caulking (.3 air change per hour)
- Double glazed windows
- Separate backup heat for each room with individual, wall mounted thermostats

Construction cost comparison

The solar rowhouses on Thompson Street were built on a fixed budget estimated on for normal construction. The solar and insulation modifications added no additional costs because they were offset by savings in other areas, namely elimination of the ductwork and central heating system normally found in such houses and elimination of exterior brick work.

Heating Cost Comparison

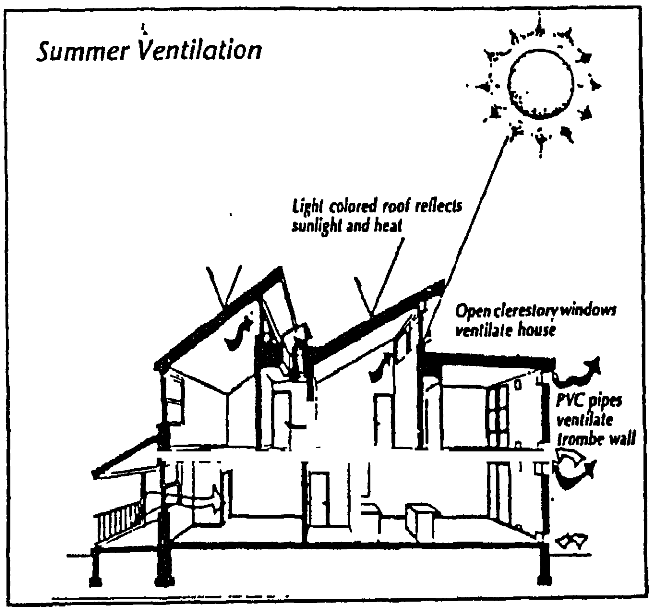
Reference case (estimated) (75% efficient gas furnace)	Solar Rowhouse (actual) (electric baseboard)	Alternate Solar Design (estimated) (natural gas heat, no clerestories)
$310/yr	$180/yr	$120/yr

ENVIRONMENTAL/HEALTH FEATURES

- Minimal lumber use
- No indoor combustion appliances.

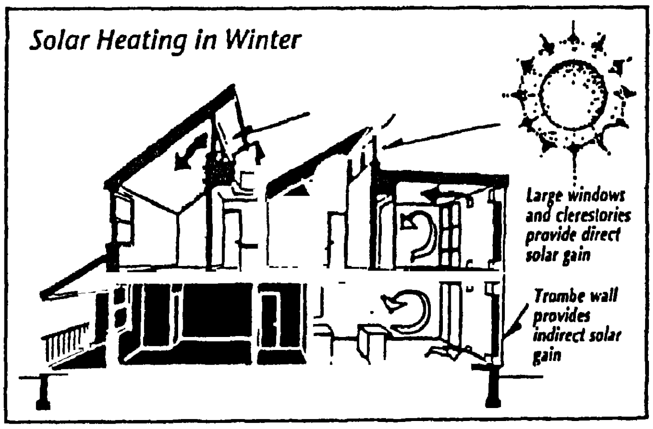
★★★

(Reprinted from 'Solar Today'; July/August 1995 Edition)



Summer Ventilation

Light colored roof reflects sunlight and heat
Open clerestory windows ventilate house
PVC pipes ventilate trombe wall



Solar Heating in Winter

Large windows and clerestories provide direct solar gain
Trombe wall provides indirect solar gain

Energy conscious building design for sustainable development

Anil Misra, Tata Energy Research Institute, Darbari Seth Block, Habitat Place, Lodi Road, New Delhi 110 003

Improved comfort conditions, long term economic gains and better environmental adaptations are some of the reasons why energy efficient design should form an integral part of building architecture. Though an energy conscious design approach may at first appear to constrain the aesthetic features of a building, the architect can transform this drawback into an advantage. This can be done by developing a better understanding of the building's interactions with the external environment and creating something which is not only visually appealing but also comfortable to live in and economical to operate. Several studies suggest that better design of new buildings could result in a 50% reduction in energy consumption; and that appropriate design intervention in the existing stock of buildings could yield energy reductions of 25%.

Taken together, and universally applied, these initiations could reduce the Indian energy bill by several billion rupees per annum and in a large number of cases can extend the level of indoor thermal comfort.

At present the current building energy use trends are cause for concern because of lack of effective energy efficiency programs in the country. Energy used for air conditioning of the commercial-buildings in India, for example, accounts for 32% of the total energy consumption (21,600 GWh in 1992) in the commercial sector. Uncertainties about energy use in buildings are echoed in the absence of adequate data for the building sector. Compared to industry and transportation, the other major energy consuming sectors, country sources for energy statistics give little detailed information about buildings. Buildings often fall into "other" category which lumps together the residential, commercial, public service and agriculture sectors. The limited coverage of the literature on energy standards reflects complexities inherent in analyzing both building energy use and building energy standards, especially in the private sector. These intricacies pose serious barriers to building energy research and complicate the development and usefulness of energy related standards.

An impediment to greater efficiency is also the fragmentation of the building trade. A commercial building project, for example, typically involves a series of hand offs: an architect designs the building but then hands it over to an engineer, who in turn specifies materials, systems and components before passing the responsibility to a contractor. Eventually the finished building is turned over to a maintenance and operations staff, who had virtually no say in the design process but probably know most about the building's day-to day performance. In such a setting construction costs are weighted much more heavily than long term operating costs. This has led to the development of low cost houses which do not take into account the comfort of building's occupants and corporate buildings which are associated with considerable energy costs. With the progress made in the technologies related to materials of construction, lighting, ventilation and airconditioning systems-architects, engineers and practitioners involved in building projects have a tendency to rely more on these rather than having a better grasp of the thermal aspects of the building design.

Understanding the basic parameters of interaction

A basic notion of the parameters which interact between the building and its surrounding is essential to better appreciate their role and importance in the building designing process for the different climate zones which can be typically classified into five groups: cool, temperate, hot-arid, warm-humid and composite. These parameters include the following:-

- thermal exchanges due to conduction,convection and radiation fluid dynamics related to ventilation
- properties of moist air, thermal comfort and hygrometry
- climatic parameters such as the geometry and energy aspects of the sun, wind, ambient temperature and humidity, condensation at the dew point
- characteristics of the materials of construction and their response to the evolution of parameters inside and outside the built space.

There are two other parameters which need to be understood and taken into consideration while analyzing the dynamic evolution of the heat transfers across the built envelope as a function of the variations in climatic parameters. One concerns the capacity of the construction material to transmit a temperature variation or their diffusivity. Most construction materials have diffusivities of more or less the same order of magnitude. For example, mortar and polystyrene have practically the same diffusivity. Though the former conducts much heat better than the latter, its temperature does not rise much due to its very high heat capacity. However, the same construction materials have very different capacities for storing and releasing heat. Mortar absorbs almost 50 times more heat than polystyrene as the latter is a poor heat conductor and has a low thermal capacity. Hollow brick is sometimes preferred as a suitable construction material which hinders the transfer of heat and its capacity to absorb heat per unit volume is lower.

Behaviour of the building envelope

After listing the various parameters which intervene in a building, one can proceed to see how the comfort level inside a built space can be achieved by playing around with them. In order to assess the behaviour of the building envelope, one should note that the building is never in steady state because :

- the ambient temperature varies over the day
- solar radiation is periodic and may be absorbed by certain opaque parts of the envelope and penetrate inside through the openings
- the internal heat gains due to metabolism, appliances, cooking etc. also vary with time
- the air velocity inside the building changes with time

This is a fairly complex dynamic problem and can be easily simulated using computer tools once the physical phenomena occurring there are taken into account.

There are certain thermal exchanges across a building envelope:

- heat exchange due to the difference between inside and outside temperatures
- incident solar radiation which varies periodically
- part of the solar radiation absorbed by the opaque wall and part of the radiation transmitted through the glazed openings
- heat gains due to internal activities
- difference of temperature between the air coming in and that leaving the building due to ventilation or air renewal

These interactions lead to a periodic evolution of the temperature inside the building and the building envelope itself absorbs and releases certain heat flux periodically. As the building envelope undergoes a cyclic change of temperature, its inside temperature can be considered to be oscillating around an average value. One can then :

- calculate this average temperature with sufficient accuracy as a function of the average values of the above mentioned parameters which influence the inside temperature

- conduct qualitative analysis to identify the measures to be taken to reduce the oscillations

- take action so that the average maximum and minimum inside temperatures lie within the comfort zone naturally or by means of minimum energy expenditure.In general, without considering the use of artificial heating or cooling, it is necessary to raise the average inside temperature of a building in cold regions or periods and reduce the average inside temperature in warm zones or periods.

Buildings in warm region or season

In order to achieve this by natural means, the designer has the option to act on the following parameters that are not independent:

- average internal gain in a matter so that it remains the minimum possible

- average solar gains through the glazing which should be the minimum

- overall conductivity which should be increased

- average ventilation rate which should also be increased

Increasing the conductivity by providing more opening area and increasing the conductivities of the opaque surfaces also result in enhancing the solar gain through some glazing and some surfaces of the envelope exposed to the sun.

The following are the systematic measures that one can undertake to reduce the average inside temperature of the buildings :

1. Reduction of the internal heat gains: The architect should not be keen on placing more artificial lighting in the name of aesthetic originality or due to ignorance about the principles of artificial lighting. Similarly, attempt should be made to reduce the internal gains in the living areas where comfort is most desired

2. Reduction of the solar radiation absorbed by the glazing : In order to reduce the solar input through the glazed areas to a minimum value, the designer should:

- avoid openings on the facades which are less inclined. One may, however, have provision for sky-lighting from the zenith in view of its quality and efficiency which allow one to reduce glazed areas.

- provide openings of reasonable dimensions and heights for natural lighting, mostly on the north and south facades and as little as possible on the east and west facades. Whenever possible, east is preferable than the west which accumulates a lot of heat due to the more elevated temperature in the afternoon. Such an arrangement which favours north-south exposure not only reduces the possibility of direct solar gains in a very simple manner such as installation of solar protection devices and even complete closing of the openings in areas which are not used during the day.

- solar radiation being very vertical whereas its azimuth is in south or north zone, the solar protection devices are simple horizontal overhangs (or extension of the roofs) with slight extension from the plane of the glazed area.

- solar radiation being closer to the perpendicular with the east-west directions, horizontal solar protection should be provided with considerable extension to be effective. As this solution tends to reduce natural lighting, a better option is to provide mobile vertical fins allowing to adjust their angle to benefit from the lighting whenever it is possible. One should not forget the use of vegetation which is very effective.

3. Reduction of the solar radiation absorbed by the walls: This can be achieved by taking the following measures:

- Designing an envelope which presents the minimum possible exposed surface area close to the horizontal and even oriented towards east or west.

- Treating the surface area of the envelope exposed to the sun with selective materials which should however have low absorptivity. For example, a lime coating is very effective as long as it is there and does not become dirty. The solution of surface treatment, theoretically satisfying, is rarely applied in practice.

- Constructing the walls of the envelope exposed to the sun, particularly those close to the horizontal, with materials of low conductivity. It is particularly important to insulate the roof terraces which transmit considerable amount of heat and lead to very uncomfortable resulting temperatures with a high radiant temperature.

- Protecting the envelope, particularly the portion which receives a lot of solar energy, by shades which blocks the solar radiation but are themselves cooled by natural ventilation.

- Protecting the horizontal parts by an attic ventilated by thermo-syphon or by the wind. The radiation emitted by this protection may necessitate the envelope to be slightly insulated.

- Protecting the vertical parts, mostly east and west, by "sun-shades" such as double-wall and vegetation.

- Using the principle of water evaporation in certain climates in hot season to cool the outside surface of the envelope. The roof-terraces covered with earth and vegetation are well adapted to regions which often face stormy weather.

4. The overall conductivity of the building envelope can be increased : After demonstrating the important need for reducing the conductivities of certain parts of the envelope which are exposed to the sun, the possibility of reducing the conductivity is low, more so while taking into account the constraint imposed by the study of the minimum area. In fact, it is the openings,which, on the other hand, should not be very important that contribute significantly to the increase in conductivity.

5. It is better management of the ventilation rate which gives the designer the power to eliminate the solar and internal gains : Higher the ventilation rate, lower will be the difference between the inside and outside temperatures. Except in the case of very high conductivity of the envelope (without any insulation), the average inside temperature decreases rapidly with the increase of ventilation rate. The average temperature is not influenced by the oscillations of temperature when the ventilation rate is constant.

Though an increase in the ventilation rate reduces the temperature difference, in climates where the outside temperature varies considerably between day and night, varying the ventilation rate brings in certain advantages. The air renewal rate may, in that case, be just the amount needed to satisfy the hygienic requirements. The ventilation rate can be increased considerably at night when the outside may be much cooler than the inside. By controlling the flow rate, it is possible to have a negative temperature difference in climates having very contrasted day and night. This is more feasible if the building has an envelope having an inside mineral layer in addition to the internal structure. The internal "inertia" of the building allows the storage of the coolness when outside air is cooler than the inside air.

All the measures mentioned above for reducing the temperature difference need not be taken simultaneously. It is up to the designer to make the suitable choice as a function of the climate, economic and cultural context, local availability of construction materials, etc. For instance in some places, well insulated roof-terrace may be economical and better adapted whereas in others a ventilated attic with a lightly insulated ceiling may be more useful and economical.

After taking all measures, if the inside thermal condition lies outside the comfort limit, one must employ an airconditioner if it is absolutely necessary to have comfort condition in the building.

In practice, a building is divided into smaller compartments with different activities. As the thermal balance and the comfort requirement in each compartment may be quite different, it is up to the architect to prepare the layout of the building according to the different usages.

Increasing the average inside temperature of a building in cold region or season

In order to achieve this by natural means, one can act on the following parameters.

- average solar gain through the glazing
- average solar gain through the opaque surfaces
- thermal conductivity by the building conception of construction
- ventilation rate by the quality of its control

By making use of the fundamental thermo-physical notions acquired, one can increase the mean inside temperature of the building by the following :

1. Reduction of the thermal conductivity without considering the increase of solar gains which affect the conductivity :

- One should design compact volumes so that for a desired volume, the surface area, particularly that which is not exposed to the sun, and the widths should be as small as possible : no unnecessary decoupling, no unnecessary lengths of links with the ground, individual houses with multiple levels, collective housing with separations between the apartments without any losses.
- One should reduce the surface transmission coefficients systematically for the surface areas, which are barely or not at all exposed to the sun and even those which are well exposed to the sun. One may use hollow materials, insulation, windows with double glazing and tight ceiling at night, insulation of the foundation and floors not connected to the envelope, wood for structure, etc. One should make the best use of the buffer spaces which reduce the conductivity, except in the case of greenhouses, the buffer spaces should be located in the north for the northern hemisphere.

2. Reducing the ventilation rate, strictly up to the level required by the hygiene :

A good ventilation management requires that:

- One must improve construction quality which allows very little air leakage by improvements in the quality of doors and windows and their positioning, elimination of opening option of windows when there is no need, placing of window shutter boxes outside, placing of dampers for all outlets with intermittent use, etc.
- One should design ventilation such that it does not depend on the velocity and direction of wind which creates some variation in the pressures. Though the objective is to design passive buildings, one can make use of a controlled mechanical ventilation which is very simple and consumes very little energy when compared with the energy it can save: air enters each room tanks to the self-regulating openings and contaminated air is sucked into the kitchen and bathroom by using a fan. These self regulating openings allow to obtain a constant air passage irrespective of the pressure differences in different zones. In cold climates, the performance of the controlled mechanical ventilators can be further improved by incorporating heat exchanger so that most of the heat contained in the contaminated air is recovered by the fresh air intake.

3. Increasing the solar gains through the glazing: while making sure it does not increase the thermal conductivity. For this,

- One should place the openings such that most of them are oriented towards south in the northern hemisphere, assuming that there is no environmental shading. In general, for regions located in the northern hemisphere where there is a problem of comfort in winter, solar energy gains across the glazing are much greater when it is south-facing as compared with east or west. The designer should avoid placing of overhangs which cut off the sun which could have reached the glazing.
- The designer should study the advantage of increasing the glazed surface exposed to the sun beyond what is necessary for natural lighting. In that case, precaution may be taken to use double glazing and shutters at night.
- One should however note that too much glazing may create discomfort at certain moment due to the effect of cold or hot wall. One way of increasing the area of glazing which captures solar energy is the incorporation of greenhouses, which act as buffer zones. The habitable space then has two types of solar gains: direct gain of solar radiation which reaches the adjacent wall after going through the glazing of the greenhouse and indirect gain due to the heating of the greenhouse.

4. Increasing the solar gains through the opaque walls: without increasing the thermal conductivity. Barring exceptional cases, it is not interesting to look for greater opaque surfaces exposed to the sun as they will also lead to higher thermal losses. On the contrary, all the surfaces of the envelope should be made minimal and as insulated as possible in order to get the minimum total conductivity.

The above discussion is based on the average values whereas in reality, one comes across irregular climates or days when the temperature and solar radiation are unfavourable and comfort cannot be attained. The whole problem is to know if in the year, it is reasonable to accept a few uncomfortable days judging from the fact that a higher investment for these few days is not justified. It may be more reasonable to tolerate a few uncomfortable days or opt for a small heating system during the worst days.

To summarize, the general reasoning consists of avoiding artificial heating or reducing it if it cannot be avoided. The designer should collect economic data to determine whether to concentrate on decreasing the conductivity, control the ventilation rate or to collect as much solar energy as possible through the openings. It is obvious that the architectural approach consisting of the search for a minimum coefficient of form (surface volume) and an intelligent placing of the openings, is fundamental as it allows to achieve an optimum without any additional cost and often at a lower cost.

Finally, one should note that it is not reasonable to design the building envelope with very good quality of opaque surfaces and mediocre quality of glazed surfaces. It is better of save money on the opaque surfaces and install double glazing with option for better thermal protection at night (shutters, for example).

Design of buildings requiring heating/air conditioning

In some situations, comfort cannot be attained inspite of all the measures taken for buildings that require heating or cooling.

Design of buildings requiring heating

All the general measures given above should be taken but with certain nuances.

In climates with little sunshine, without the main source of heat through the glazing, a high inertia by absorption is not a necessity. The glazing area, appropriately oriented, should not exceed that required for natural lighting.

First of all, one should strive to get as low an overall conductivity as possible for the envelope, fully protected from air leakage and with controlled ventilation, and if possible, provide option for recovery.

If the building is only occupied periodically, it should be designed with a low inertia by absorption in order to eliminate the heating during periods of non-occupancy and reheating the building rapidly before its usage.

If it becomes uncomfortable due to high temperature in the hot season, a certain inertia by absorption may be required but this could be low as long as the orientation and the glazing are well protected, not letting the solar energy penetrate through the openings, and if the portions closer to the horizontal are treated against the solar radiation which is generally achieved by the use of insulation in cold regions.

Designing of buildings requiring cooling

Here too, all the measures given in the previous section should be considered but with certain nuances.

In a general manner, the moment a constant temperature is imposed by airconditioning, there is no need for inertia in the building. The designer should take care to have an envelope with a low overall conductivity, protected from air leakage and ventilation should be minimum and controlled. One can distinguish two cases where air conditioning is required.

- Some climates require airconditioning throughout the year. The above conclusions are valid and the building need not be inert. If it is only occupied periodically and if the night temperature is above the comfort temperature, the building should conceived with as low an inertia as possible in order to quickly cool the space without requiring great power.
- There are climates which require airconditioning only during one period in the year and may even face the cold of winter. In order to have a minimal period of airconditioning only and to avoid the need for heating, the buildings should have a sufficient inertia by absorption (inertia of transmission already existing with the insulation).

Concluding remarks

A few fundamental notions concerning the interaction of the building with its environment are elaborated here which need to be taken into account at the designing stage itself in order to come up with a fairly suitable building which will not only overcome the local climatic constraints but also make use of the prevailing conditions to render the living space thermally comfortable to live in while consuming practically no additional energy.

It should be stressed here that there is a need to return to the "good old days" of the simpler ways of doing things which worked very well in the past before one thought about the artificial means of comfort conditions. In this context, it is essential that one makes use of the local materials and skills which will allow to minimise the cost of construction as well. Efforts made at each individual level will go a long way in reducing the rapid depletion of fossil fuels at the planetary scale and help in sustaining the growth of the developing countries which are striving to achieve the level of comfort in the industrialised world.

★★★

Blueprint for Better Buildings

David Malin Roodman, Research Associate, Worldwatch Institute, 1776 Massachusetts Avenue, NW, Washington, DC 20036-1904, USA; Nicholas Lennsen, Research Associate, E Source, 1033 Walnut Street, Boulder, Colorado 80302-5114, USA.

Modern buildings, like other artifacts of industrial civilization, represent an extraordinary achievement with a hidden cost. They make life easier for many today, but their construction and operation inflict grievous harm upon the environment, threatening to degrade the future habitability of the planet. Building accounts for one-sixth of the world's fresh water withdrawals, one quarter of its wood harvest and one fifth of its material and energy flows. This massive resource has massive side-effects-deforestation, air and water pollution, stratospheric ozone depletion, the risk of global warming. Moreover, up to 30 percent of new and renovated buildings suffer from "sick building syndrome", subjecting occupants-who spend up to 90 percent of their time indoors-to unhealthy air.

Climate-sensitive design

The knowledge, materials and technologies required to remedy the shortcomings of conventional buildings are readily available. For example, buildings in temperate region can get most of their heat from the sun. The technique for accomplishing this dates back at least to the ancient Greeks, who ,when confronted with a fuelwood supply crisis, literally turned to the sun for heat, orienting many of their buildings with large south-facing openings. Likewise, ancient Romans, Chinese, Japanese and Anasazi Indians of North America all paid careful attention to the location of the sun when planning their buildings.

Contrary to popular perception, compact cities can exploit solar energy effectively. Passive solar residences can be built as densely as 35 to 50 dwellings to the hectare (14 to 20 per acre), yet a typical US residential suburb is zoned for no more than 10 homes per hectare (4 per acre). The German Weimar Republic, squeezed for cash in the 1920s by billion-dollar war reparations, demonstrated the suitability of this approach when it built whole neighborhoods of home that captured the sun's heat to save on energy expenditures. And modern-day Berlin is again experimenting with the idea in one project-a group of six-storey apartment buildings with south-facing solaria.

Some architects today also exploit what is known as daylighting, which uses skylights, atria and other techniques to reduce the need for electric light. Studies show, not surprisingly, that natural light is the best type of light for the human eye, and that proximity to windows improves well-being. For schools and offices that are occupied primarily during the day, daylighting is particularly cost-effective, cutting peak electricity demand. At the same time, it improves lighting quality, aesthetics and worker satisfaction.

Taken as a whole, climate-sensitive design using available technologies in the United States could cut heating and cooling energy use by 70 percent in residential buildings, and by 60% in commercial buildings, according to scientists at the US Department of Energy's National Renewable Energy Laboratory (NREL) in Golden, Colorado.

Existing examples suggest that these estimates are quite conservative. For example, by using solar orientation, thermal storage and superinsulation in their new home, two NREL researchers cut heating bills by 97.5 percent compared to their neighbors'.

Not far away, the Rocky Mountain Institute's headquarters gain 99 percent of its heat from the sun and the people and appliances inside, despite a frigid mountain climate.

Appropriate technologies

In addition to using energy more efficiently, buildings can tap renewable, on site supplies.Solar water heaters offer a simple method of producing hot water on site without burning fossil fuels or splitting atoms. More than 900,000 solar units in Israel heat 83 percent of the country's domestic hot water, and in Japan, some 4.5 million units were in place by 1992. Residents of Botswana's capital, Gaborone, have installed more than 3000 solar water heaters, displacing nearly 15 percent of the country's residential electricity demand. Some 30,000 are in use in Columbia, 17,000 in Kenya and 10,000 in the Netherlands.

Buildings can also supply their own electricity-and do so without producing carbon dioxide or nuclear waste. Solar photovoltaic cells produce electricity from sunlight without no moving parts. Driven by improvements in technology, as well as the adoption of mass production techniques, the cost of electricity from solar cells has fallen more than 90 percent since 1980.

As solar cell prices continue to decline, integrating them right into a building's facade or roof, rather than attaching separate solar panels, may soon become common. Companies in Japan, Switzerland and the United States are testing new types of solar cells that also function as roofing shingles or tiles. In Western Germany, rooftop photovoltaics on existing buildings could generate up to 25 percent of the region's electricity. Even in the cloudy United Kingdom, the potential in recladding building surfaces with solar cells is estimated to equal half the country's electricity supply.

Benefits of ecological design, selected samples :

Building Year completed	Measures Undertaken/Cost	Outcome (Annual gains)
Reno Post Office, Reno, Nevada, 1986	Lighting upgrade and lower ceiling height to improve light quality and efficiency at the cost of $ 300,000	$50,000 in energy and maintenance; $ 500, 000 in productivity
Pennsylvania Power and Light, Allentown, Pennsylvania, early 1980s	Lighting upgrade and reorientations of fixtures in drafting engineers office at cost of $ 8,362	73 percent drop in energy and maintenance, $ 42,240 (13 percent) gain in productivity
Internationale Nederlanden Bank, Amsterdam 1987	New buildings used energy-efficient design for lighting, heating and elimination of air conditioning; operable windows; thermal storage; cogeneration system; and avoidance of toxic materials at added cost of $ 700, 000	$ 2.4 million in energy; $1 million (15 percent) drop in absenteeism
Village Homes, Davis, California, 1957-1981	220-home subdivision designed to capture 50-75 percent of heat from sun, incentives for nonmotorized transportations, natural drainage and edible landscape	12 percent premium in average home value
Lockheed Building 157, Sunnyvale California, 1983	New building used daylighting, efficient lights and an open layout encourage worker interaction at added cost of $ 2 million	$ 500,000 in energy; $ 2 million (15 percent) drop in absenteeism; 15 percent gain in productivity
Esperanza del Sol, Dallas, Texas, 1994	New residential constructions of low-income, energyefficient and solar-oriented houses at cost of $12 added annually to mortgage payments	$450 in energy

Better for living, working

The pragmatic pitch for resource-efficient building has always been that it saves money on utility bills. Yet as significant as these savings can be, there is a growing realization within the building industry that the full benefits of ecological design are many times greater.

Such design can greatly enhance the qualities buildings ought to have, making them not only more affordable, but also more pleasant and healthy-productive to work in, and desirable to live in. Translated into dollar terms, the increases in worker productivity or home value alone can far exceed the utility bill savings (see table).

Confronting the challenges

As much as it is changing, however, the industry still has far to go. Many of the problems it contributes to, from the risk of climate change to species and habitat destruction, are worsening at an accelerating rate. Given the magnitude of these problems, institutions that can take the long view, such as governments, educators and the lenders that broker most capital for construction, can all play a critical role. In fashioning a comprehensive strategy, they need to combine a number of tactics, including tightening building codes, taking steps to educate professionals and the public and creating fiscal incentives that reward good building

Building codes

Governments have long taken an active role in the building sector through construction codes to ensure that structures are resistant to earthquakes and fires. Energy and water-use codes and appliance standards, which, for example set minimum levels of insulations or maximum levels of water use,have also appeared in the last 20 years. In 1978, California adopted a new energy code that had saved $11.4 billion on energy expenditures by 1995 and is predicted to save another $43 billion by 2011. Some countries are extending building codes to protect indoor air quality. The European Union has developed uniform standards and the US government released preliminary regulations in 1994.

Codes are crucial for developing countries, where building booms are driving up energy and water use. Enforcing codes, though, can be difficult, especially in developing countries, where governance is often weak. Since 1986, for instance, China has required new apartments to be 30 percent more efficient and in 1993 it raised the level to 50 percent, but builders and local governments alike have ignored the code. Even in affluent countries-for example in Dade County, Florida, where Hurricane Andrew came ashore, codes are sometimes disregarded.

Codes and standards, though important, do little to educate consumers or encourage builders to innovate beyond the norm, which is essential to the development of a vibrant, environmentally conscious building market in the long run. As New York architect Randolph Croxton notes, any developer who proudly claims that a structure "meets every code" may actually be making a confession: "If I build this building any worse, it would be against the law".

Education essential

One of the first steps towards a more fundamental transformation of the industry will be changing the values it holds as a culture and the process that transmits them, namely, education. Architectural and engineering students, in particular, need to learn to care about how their buildings work after they are built, not just how they look on the drawing board beforehand. Post-occupancy evaluations of buildings, now done infrequently, need to become routine, so that designers receive feedback from building users and managers on the ways that their buildings affect people and on how well they survive the passage of time. In addition, professional schools need to teach students about integrative, interdisciplinary design processes.

Government and industry groups should also work to educate practicing professionals. The 1994 success of the environmental code of practice published in the

United Kingdom suggests that in many countries they will find a receptive audience. In 1991,the American Institute of Architects began publishing an Environmental Resource Guide that covers energy, land use and detailed assessments of the impacts of various materials.

Equally necessary are efforts to educate the general public in order to stimulate consumer interest in environmental techniques and technologies and accelerate their dissemination and commercialization. At relatively little cost, high-profile projects like the Internationale Nederlanden Bank headquarters in Amsterdam (see table) can have large impacts. The bank is now the best known building in the Nederlands, according to national surveys.

Other countries are also launching demonstration projects. On Earth Day 1993, President Bill Clinton announced the "Greening of the White House". By late 1994, some 50 measures have been initiated, including lighting and water fixture upgrades, with additional steps planned for the next 20 years. The demonstration value of a project like this-seen by 1.5 million visitors a year- is far greater than the immediate savings.

Design contests intended to spark innovative solutions are also catching on around the world. The Canadian Government, already successful with a residential competition, has launched a contest for new commercial buildings. Three winning designs are now being built, with all using low-impact materials and consuming half the normal amount of energy. Governments have also run competitions in New Zealand, as well as in France, where 700 homes based on the winning design will be built.

Rating and levelling

To push these new approaches further into the building marketplace, some governments and industry groups are using voluntary rating systems. The UK government initiated a rating program in 1991, awarding points for features that go beyond code requirements-by saving energy and water, increasing recycled materials use, lowering toxic materials use or reducing local environmental impacts. By mid-1994, more that 25 percent of new commercial buildings were being rated and government had developed programs to rate existing commercial buildings and new homes. Some British real estate agents now use high environmental marks to promote their properties.

In the United States,the non-profit Green Building Council expects to launch a rating scheme for commercial buildings in 1995. In countries with great climatic and geographical variety, such as the United States, rating systems should vary regionally, leaving room for local organizations to contribute. Austin, Texas, for example, already has a 10-year old Green Builder program that, among other things, rates residential construction.

A variant of rating is labeling-instead of getting graded, buildings simply pass or fail. In 1980, the Canadian government began a voluntary certification system for energy-efficient houses. Although only 8,000 homes have undergone certification to earn the "R-2000" imprimatur, the program has improved mainstream construction by commercializing and popularizing a number of efficient technologies. And in 1994, the government added requirements on materials selection and indoor toxic sources. In general, creators of rating and labeling systems should be prepared to revise them as scientific understanding of environmental problems improves and as new materials and technologies reach the market.

Financing know-how

Support from financial institutions is also crucial to transforming the building market. Most building owners buy their properties on credit, so banks, insurers and other lenders can substantially influence what gets built. Usually lenders see innovate projects as risky and subject them to costly delays or higher interest rates. A few banks, however, have realized high-quality, resource-efficient buildings hold their value better and leave owners more money to repay loans, making them a better risk. The Bank of Montreal, for example, cuts the interest rate on loans for R-2000 homes by one-quarter point. In the United States, "energy-efficient mortgages," which reduce the income requirements on energy-efficient homes, have been available through federal and state lending agencies as well as private banks for more than a decade. Most U.S. financial institution, though, resist making more significant changes. Sweden, in marked contrast, has subsidized loans for energy efficient homes for twenty years, which partly explains how the Swedish building industry has reached such high standards of efficiency. And in early 1995, Sweden's largest housing bank, Hypoteksbanken, announced that, having sustained massive losses from sick building syndrome, it plans to lend money only for "green" buildings. For the same reason, insurance companies could also begin to reward healthier buildings with lower liability coverage premiums.

Multilateral financial institutions, led by the World Bank should help developing countries improve their fast-growing building stock.The bank lends hundreds of millions of dollars each year to East European and developing countries for projects relating to housing. In its efforts to insure basic services, the bank has only recently started to consider specific measures to improve energy and water efficiency.

Utility involvement

Electric, natural gas and water utilities can also play a role in ensuring efficient use of natural resources, in order to reduce expenditures, on fuel and new power and water treatment plants. Some electric utilities give rebates to building owners for upgrading lights, appliances and mechanical systems. But utilities can also be more pro-active, targeting new building construction.

One approach would be a "feebate" system that charges less-efficient structures for connections to energy and water utilities and then uses this revenue to reward developers of more-efficient buildings. A few North American utilities are trying a similar method, helping home buyers with the down payments on new houses that are energy-efficient. New Brunswick Power tenders rebates for R-2000 homes, which is one reason these now account for 20 percent of the new houses built in that province- the highest rate in Canada.

Government initiatives

Just as utilities are reaching into the building process, government can develop constructive partnership with industry. One consequence of the fragmentation of the building business in most market economics is that architectural, engineering and construction firms are too financially insecure to invest in research and development. Research needs to focus not only on new technologies but also on techniques for integrating them.The Swedish Government spends more per capita on building research than most countries, another reason that homes there are so energy-efficient.

The US Environmental Protection Agency has initiated an innovative set of voluntary programs to spur businesses to upgrade their facilities. It serves as a clearinghouse for information on new technologies and provides tools for predicting the economics of their deployments in specific situations. The Green Lights program, which has more than 1500 participants so far, will eventually reduce lighting energy use by about half in at least 5 percent of US commercial floor space. The Energy Star Buildings program, inaugurated in 1994, carries the approach further, guiding building managers through a series of steps to improve air quality and cut energy use in existing structures an impressive 50 percent all cost-effectively.

Government should also execute fundamental reforms on fiscal policy. Currently, most governments subsidize, rather than tax, pollution and resource extraction. The US government gives the mining industry a $500 million annual tax break. The German government spends $4.9 billion a year subsidizing coal production at more than four times the world price, and 36 percent of this coal is burnt to provide heat and power to buildings. Subsidies for coal and hydropower development are also endemic in developing countries, where the average price of electricity-30 percent of which is used in buildings-fell from 7.0 cents in 1983 to just 4.9 cents only five years later.

Governments need to gradually eliminate such subsidies and reform tax policy so that the true economic and social costs of depletion and pollution are passed on to those who benefit from it. If governments balance such increases with cuts in other taxes- on labor, for example- the net impact could be positive, providing simultaneous incentives for efficiency and employment. Governments might also channel a small percentage of the money into research and development, helping to accelerate the expansion of resource-efficient and healthy construction.

Around the world, the challenge for policymakers, educators and lenders resembles that facing builders. No single measure, whether tax reform or solar design, will fully rectify the fundamental problems with modern buildings. Rather, what is needed is a broad set of changes in the way everyone involved does business. Like an integrative design team, society can enter the process of change with a rough sense of the path it will take, but it needs a clear idea of its destination. The goal is one all can easily agree on-creating a secure home for humanity.

★★★

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WORKSHOP ON
SOLAR PASSIVE ARCHITECTURE
DATE : 29th MARCH, 1996

LIST OF PARTICIPANTS

Sl. No.	Name of Participants	Department
1.	Shri P. Shyam	Chief Engineer, RWD, Itanagar.
2.	Shri T. H. Tayung	Chief Engineer (E/Z), PWD, Itanagar
3.	Shri R. Nagdev	Sr. Architect, PWD, Itanagar.
4.	Shri D. C. Nath	Jt. Director, Planning & Development Deptt., Govt. of Arunachal Pradesh, Itanagar.
5.	Shri D. K. Haldar	Survey of Works (E/Z), PWD, Itanagar.
6.	Shri J. P. Parashar	Director (SLUB), RWD, Itanagar
7.	Shri S. R. Dey	Survey of Works, PHED, Itanagar.
8.	Shri Taba Tadir	Survey of Works (E/Z), PWD, Itanagar.
9.	Shri T. Ette	Superintending Engineer (Civil), Deptt. of Power, Itanagar.
10.	Shri A. K. Atre	Joint Director (RE), Department of Rural Development, Itanager.
11.	Shri H. K. Shalla	Deputy Secretary, RWD, Govt. of Arunachal pradesh, Itanagar.
12.	Shri K. C. Dhimole	Project Director (Energy), RWD, Itanagar.
13.	Shri B. S. Pandey	Executive Engineer, BRTF, Itanagar.
14.	Shri M. Ngowdir	Executive Engineer, IFCD, Itanagar.
15.	Shri Moto Garo	Executive Engineer, PWD, Itanagar.
16.	Shri P. D. Kashyap	Leacturer, NERIST, Itanagar.
17.	Ms. M. Singh	Architect, PWD, Itanagar.
18.	Shri M. M. Borah	SFRI, Govt. of Arunachal
19.	Shri Kauto Eshi	Asstt. Architect, O/O the Sr. Architect, PWD, Itanagar.
20.	Shri D. Tsering	Architect, PWD, Itanagar
21.	Shri A. Bhattacharyya	Project Officer, RWD, Doimukh.
22.	Shri N Biswas	Asstt. Engineer, IFCD, Itanagar.
23.	Shri T. S. Sian	Asstt. Engineer (Mech), RWD, Itanagar.
24.	Ms. Nandita Hazarika	Scientist, TERI, Guwahati.
25.	Shri Debajit Mahanta	Asstt. Scientific Officer, Arunachal pradesh State Council for S & T, Itanagar.
26.	Mrs. Jarum Ette	Secretary General, Arunachal Pradesh Women Welfare Society, Itanagar.
27.	Shri P. K. Bhattacharjee	Jr. Engineer, (IREP cell), RWD, Doimukh.
28.	Shri S. Choudhury	Jr. Engineer (Energy), RWD, Itanagar.
29.	Shri Indrasish Paul	Technician (SPV), RWD, Itanagar.

GUEST SPEAKERS.

1.	Shri Anil Misra	Tata Energy Research Institute, New Delhi.
2.	Shri A. K. Basu	Project Manager, M/s. Gherzi Eastern Ltd., Calcutta.
3.	Shri S. P. Pramanik	Senior Architect, M/s. Gherzi Eastern Ltd., Calcutta.